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UNIVERSITY OF FLORIDA GRADUATE ENGINEERING AND
RESEARCH CENTER
IN COLLABORATION WITH THE
AIR FORCE RESEARCH LABORATORY MUNITIONS DIRECTORATE
FOR THE

RESEARCH INSTITUTE FOR AUTONOMOUS
PRECISION GUIDED SYSTEMS

(F49620-00-1-0288)

1 MAY 2002- 31 March 2003

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**RESEARCH INSTITUTE FOR AUTONOMOUS
PRECISION GUIDED SYSTEMS**

F49620-00-1-0288

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Objectives

The aim of this project is to leverage the manpower resources dedicated to basic research in technologies relevant to autonomous precision systems at the Air Force Research Laboratory Munitions Directorate (AFRL/MN). This is accomplished by inviting scientists from the University of Florida and other institutions around the world to participate in this Research Institute at the University of Florida's Graduate Engineering & Research Center (UFGERC) for selected time periods. During their stay they work alongside AFRL/MN scientists on basic research issues relevant to the Air Force mission. This government operated/collaborator assisted (GOCA) concept is consistent with the aims and procedures espoused by the STW-21 initiative of the AFRL. The selection of research focus areas and invited participants reflects a partnership within which the UFGERC, AFRL/MN, and AFOSR collaborate as a team.

The key to quality research is the achievement of a critical mass of scientists in the technology thrust fields in the particular disciplines of importance to AFRL/MN's mission. In order to arrive at the requisite depth of manpower in a time of consolidation it is necessary to bring together and combine the strengths of the university and the military laboratory. Such an intellectual environment is conducive to attracting top graduate students and post-doctoral fellows to the Research Institute. Not only is the creativity from such participants important to the scientific undertaking, but it is also a source for possible additions to the permanent staff of AFRL/MN. The joint activity represented by the Research Institute also brings the possibility of leveraging financial support for the research by interested sponsors outside the Air Force.

Status of Effort

The Research Institute, initiated on May 1, 2000, is functioning effectively in bringing together outstanding scientists and their students in concentrated personal interactions with AFRL/MN scientists on a daily basis. The collection of visiting scientists from different, but related, fields has been fruitful in fostering multidisciplinary cooperation.

The performance on this project has been reported in several previous reports: 05/00 – 09-00, 10/00 – 7/01, and 08/01 – 05/02; the latter two being presented at the AFOSR Contractor's Meetings for those years. This report covers the final year of performance on the present contract, which has been renewed for another three years, starting April 1, 2003.

Accomplishments

1. Website

A website explaining the purpose, structure, and activities of the Research Institute for Autonomous Precision Guided Systems has been established on the GERC website at the following address: www.gerc.eng.ufl.edu/RIAPGS.htm.

2. Research Focus Areas

During the reporting period, Research Institute activities were concentrated on three research focus areas in which the team members have an established scientific base:

- **Innovative Computational Techniques Applied to Air Force Problems**

Fundamental science issue: The capability of modeling strong discontinuities in solids to construct well-posed models of strain localization and failure and the numerical resolution of multiple length scales.

Current status: Current models exhibit mesh dependence, i.e., never converge, and do not resolve localization zone structure.

Background and Statement of the Problem: The Air Force is interested in the development of smaller, smarter, higher precision, more effective air delivered systems. Reduction in system size generally implies a smaller payload, which runs counter to the desire for increased effectiveness. One avenue of maintaining payload effectiveness is by focusing detonation and preferentially fragmenting or cutting liners and case materials, i.e., a multi-mode warhead. Some important effects requiring study include initiation and interaction of detonation waves, their explosive interaction with metal, shock propagation and attenuation in metals, metal damage under combined deviatoric and spherical stress, and metal fracture. In the area of detonation modeling and interaction, resolving the detonation wave structure, including the von Neumann spike and the details of the wave interaction region, are thought to be important for some concepts. Similarly, knowledge of the details of the interface between explosive and metal to be modeled is needed. At a minimum, this includes full thermomechanical coupling, but also perhaps includes hydrodynamic instabilities in the material interface. Modeling of the metal response to explosive loading must resolve the damage evolution and failure under fairly complex multidimensional stress states and at extreme rates.

Relation to AFRL/MN's mission: High confidence computational design capability for exploring and evaluating adaptable warheads providing tailored and directional lethality options.

- **Thermo-Mechanics of High-Speed Penetration of Geo-Materials & Concrete**

Fundamental science issue: Understanding high rate friction and abrasion, coupled with related thermodynamic properties, arising from the penetration process.

Current status: No theoretical models are currently available to predict penetrator nose erosion and resulting shape change that contributes to observed trajectory deviations.

Background and Statement of the Problem: Most hardened and deeply buried targets reside in, or are constructed of, geologically derived materials. Although penetration into these media have been studied for many years, it has been difficult to precisely define the constitutive behavior of geological materials under the high confining pressures and high rates of loading experienced during a penetration event. High velocity penetration mechanics experiments performed at AFRL/MN have demonstrated monotonic increases in penetration depth with striking velocity. However, significant erosion is observed in the nose region of the penetrators, a critical region governing penetrator behavior during the penetration process. As such, the increased nose erosion detected at higher velocities is deemed to contribute to the instability associated with penetrator trajectory at higher striking velocities.

Relation to AFRL/MN's mission: Provide a methodology for a nose design that controls mass loss, or avoids the degrading effect that mass loss and corresponding shape change has on the penetration process.

- Integrated Guidance/Cooperative Attack

Fundamental science issue: Develop a theoretical model for cooperative control of multiple dynamic agents that can assess performance of control and heuristic based solutions.

Current status: There is a lack of models uniting centralized control, information, transmission, and local solutions.

Background and Statement of the Problem: Some theory for decentralized cooperative control has been developed but it does not include observability and controllability. These attributes must be included to arrive at some degree of autonomy for a collective agent swarm. Similarly, information theory metrics for describing transmission of noisy states are required. Decision-making game theory has been developed for multiple agents within a hierarchy solving a common problem. At present, the best partitioning of data for solution arises from inference, while it is desired to proceed to solving the Bayesian problem, given the partition. Sensitivity studies are needed to identify what states/controls need to be observed, e.g., Lagrangian (dual) analysis and adjoint methods.

Relation to AFRL/MN's mission: Cooperative attack weapons are groups of inexpensive, smart, flying agents that cooperate in their endeavors to detect, classify, engage, and destroy targets that are difficult to detect because they are small, hidden, or moving. Achieving on-line efficient control for large numbers of agents is necessary to complete this mission.

3. Workshops

An important role for the Research Institute is the dissemination of information about new research areas to help hone the cutting edge of AFRL/MN research. To this end workshops are held, as needed, in the research focus areas. The general outline for the conduct of the workshops is described below:

(a) Review of Technical Agenda

- Research Institute Overview
- Vision for the Research Institute
- Background and Theme of the Workshop
- Status of current experimental data
- Status of analytic capability
- Formation of breakout groups on key issues
- Identification of action items by working groups in terms of stair-step charts

(b) Desired Outcome of the workshop

- Inform invitees of the opportunity to conduct basic research with MN through a variable-term visiting appointment at the Research Institute.
- Inform attending AFRL/MN scientists about research directions that will best position them to carry out their 6.1 research mission.

(c) Results of Workshop

- AFRL/MN scientists obtain information on potential high-payoff research directions.
- AFRL/MN scientists form working relationship with invitees.
- Invitees are encouraged to participate in longer-term visits to work with AFRL/MN scientists on a specific problem arising out of the workshop.

(d) There were two workshops held during the reporting period:

- Design and Use of Flight Vehicles for a Cooperative Attack Test Bed, July 15-18, 2002
Rob Murphey, AFRL/MN: "Approach of Workshop (Motivation)"
Belinda King, AFOSR: "An Introduction to the Center for Agile Autonomous Flight"
Discussion Lead: Jonathan How, MIT, on "Scale (how, why and when)"
Discussion Lead: Juan Alonso, Stanford, on "Aeroforms and Actuation"
Discussion Lead: Pete Ifju, UFL, on "Fabrication (methods and materials)"
Discussion Lead: Juris Vagners, U Wash-Seattle" on "Propulsion"
Discussion Lead: Eric Johnson, GA Tech, on "Avionics"
Discussion Lead: Jason Speyer, UCLA, on "Instrumentation and (non-avionics) sensors"
Discussion Lead: Eric Feron, MIT, on "Systems and Trades"
Belinda King, AFOSR: "Reduced Order Controllers for Systems Modeled by Partial Differential Equations: Approaches, Challenges, and Questions"
Lizette Zietsman, VA Tech: "Functional Gain Computations: 1D Parabolic Eq. with Non-Uniform Meshes with Applications to Flow Control"
Jason Speyer, UCLA: "An Instrumentation System Applied to Formation Flight"
Stefano Soatto, UCLA: "Dynamic Vision"
Kristi Morgansen, U. Washington: "Oscillatory Feedback Control with Application to Underwater Locomotion"
Eric Feron, MIT: "Agile Autonomous Air Vehicles"
S. Krishnaprasad, UMD: "Geometric Methods for Formation Dynamics and Control"
Pavlo Krokhmal, UFL: "Conditional Value-At-Risk in Stochastic Programs with Poorly Defined Distributions"
Michael Zabarankin, UFL: "Analytical and Discrete Optimization Approaches in Optimal Trajectory Generation"
Timothy Horiuchi, UMD: "Microchip-Optera: Building a VLSI-Based Bat Echolocation System"
- Flow Control for Agile Autonomous Flight, March 24 – 25, 2003
John Burns, Virginia Tech: Discussion Forum II Co-Chair
Lawrence Ukeiley, University of Mississippi
Max Gunzburger, Florida State University
Andy Kurdila, University of Florida

Ari Glezer, Georgia Tech: Discussion Forum I Co-Chair
John Kim, UCLA
Val Kibens, Boeing: "Industry perspective"
Daniel Miller, Lockheed Martin: "Flow Control on Next Generation Air Vehicles"
Lou Cattafesta, University of Florida: Discussion Forum II Co-Chair
Wei Shyy, University of Florida
Dan Henningson, KTH
Mark Sheplak, University of Florida
Jim McMichael, GTRI-ATAS
Tom Corke, Notre Dame
David Williams, IIT
Glenn Gebert, Lockheed Martin: "Industry Perspective"
Katie Camp, Virginia Tech
Lisa Stanley, Montana State University
Clifford Rhoades, AFOSR
Belinda King, AFOSR: "Basic Research in Flow Control – An Appraisal"
Johnnie Evers, AFRL/MN: Guidance & Control for Autonomous Micro-Air Vehicles"
John Anttonen, AFRL/MN: "Applications in Flow Control for Micro-Munitions"
Tom Beutner, AFOSR
James Myatt, AFRL/VA

4. Technical Review Meeting

A technical review meeting was held in December 2002 and was attended by 33 people. There were 3 papers by the AFRL/MN scientists and 2 papers by AFOSR scientists describing the focus areas covered by the Research Institute and 12 papers by Research Institute faculty describing the specific results of their efforts in the focus areas, as listed below.

"Biologically Inspired Guidance, Navigation, and Control", Mr. Johnny Evers, AFRL/MN, Eglin Air Force Base, FL

"Vision-Based Control of Micro-Air-Vehicles: Problems and Progress", Dr. Andrew Kurdila, Department of Mechanical & Aerospace Engineering, University of Florida, Gainesville, FL

"Adaptive Nonlinear Guidance and Control for Future Autonomous Munitions", Dr. Anthony Calise, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA

"Distributed Control in Adversarial Environments", Dr. Jeff Shamma, Mechanical & Aerospace Engineering Department, University of California, Los Angeles, CA

"Coordinated Control of Agile Autonomous Vehicles with Dynamic Communication", Dr. Kristi Morgansen, Department of Aeronautics & Astronautics, University of Washington, Seattle, WA

"Implications of Agility on Cooperative Control", Dr. Robert Murphey, AFRL/MNGN, Eglin Air Force Base, FL

"Agile Flight: What We Can Learn From Insects", Dr. Rafal Zbikowski, Department of Aerospace, Power & Sensors, Cranfield University, Shrivenham, UK

"Analytical and Discrete Optimization Approaches in Optimal Trajectory Generation", Dr. Michael Zabrankin, Industrial and Systems Engineering Department, University of Florida, Gainesville, FL

"Conditional Value-at-Risk in Stochastic Programs with Poorly Defined Distributions", Dr. Pavlo Krokhmal, Industrial and Systems Engineering Department, University of Florida, Gainesville, FL

"Neural Network Algorithms for Navigation Processing", Dr. Eric Sutton, Department of Electrical & Computer Engineering, University of Florida/GERC, Shalimar, FL

"Overview of Research on Agile Autonomous Flight", Dr. Belinda King, AFOSR/NM, Arlington, VA

"Micro and Small UAV Research at the University of Florida", Dr. Peter Ifju, Department of Mechanical & Aerospace Engineering, University of Florida, Gainesville, FL

"Systems Research for Cooperative Wide Area Search Munitions", Dr. Marc Jacobs, AFOSR, Arlington, VA

"Thermomechanics of High Speed Penetration", Dr. Mary Hughes, AFRL/MN, Eglin Air Force Base, FL

"Thermomechanics of Impact and Penetration, Dr. Sathyanaraya Hanagud, School of Aerospace Engineering", Georgia Institute of Technology, Atlanta, GA

"Thermodynamics and Kinetics of Friction and Wear in KE Penetrators", Dr. Janusz Klepaczko, Laboratory of Physics & Mechanics of Materials, Metz University, Metz, France

"Development of Semi-Analytical Methods for Simulation of High-Velocity Impact", Dr. Oana Cazacu, Department of Mechanical and Aerospace Engineering, University of Florida/GERC, Shalimar, FL and Dr. Nicolaie Cristescu, Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL

5. Seminars

There were 31 invited formal seminars conducted under the auspices of the Research Institute during the reporting period:

- Seminar series on "Dynamic Fracture" including talks by: N. Cristescu, University of Florida; O. Cazacu, University of Florida; U. Hunsche, Federal Institute for Geosciences

& Natural Resources, Hanover, Germany; J. Klepaczko, Metz University, Metz, France; F. Hansen, Andia Corporation, New Mexico. May 6, 2002

- "Agile Autonomous Flight", Dr. John Burns, Virginia Tech. May 15, 2002
- "Cooperative Vehicle Control", Dr. Raffaelo D'Andrea, Cornell University. May 22, 2002
- "Optimal Decisions in Uncertain Environment: Routing and Weapon-Target Assignment Problems", Dr. Stanislav Uryasev, University of Florida. May 28, 2002
- "Micro-Power Generation and Ceramic Micromachining", Dr. Shumi Tanaka, Tohoku University. June 10, 2002
- "Thermodynamics and Kinetics of Wear in KE Penetrators", Dr. Janusz Klepaczko, Metz University, Metz, France. June 14, 2003
- "Proper Orthogonal Decomposition Based Optimal Neurocontrol Design for Distributed Parameter System", Dr. S. Balakrishnan, University of Missouri-Rolla. June 27, 2002
- "Information Flow and Cooperative Control of Vehicle Formations", Dr. Richard Murray, California Institute of Technology. June 27, 2002
- "Micro-Mechanical Studies of Metal Powder Compaction", Dr. Pia Redanz, Technical University of Denmark. July 2, 2002
- "Coordination and Control for Cooperating UAV's", Dr. Jonathan How, Massachusetts Institute of Technology. July 2, 2002
- "Adaptive Curve Evolution Approaches for Image Segmentation" & "Model Predictive Control for Dynamic Unreliable Resource Allocation", Dr. David Castanon, Boston University. July 2, 2002
- "Modeling and Prediction of Ductile Failure in Metals Using a Continuum Damage Mechanics Based Approach", Dr. Nicola Bonora, University of Cassino, Italy. August 8, 2002
- "Impact Responses of Composite Structures: Experimental, Analytical and Finite Element Analysis", Dr. Anwarul Haque, University of Alabama, Tuscaloosa. August 15, 2002
- "Decentralized Control Information Structures Preserved Under Feedback", Dr. Sanjay Lall, Stanford University. August 19, 2002
- "Robust Estimation and Control with Partial Information", Dr. Ben Fitzpatrick, Tempest Technologies LLC. August 20, 2002
- "Nonstationary and Networked Control of Heterogeneous Systems", Dr. Geir Dullerud, University of Illinois. August 23, 2003
- "Vector Inversion Generators for the Production of Gigawatt Level RF Bursts", Dr. Frank Rose, Radiance Technologies, Huntsville, AL. August 29, 2002
- "Initiation of Instability on a Fault System Under Slip Dependent Friction", Prof. Ioan Ionescu, University of Savoie, France. October 7, 2002
- "Flapping Wing Micro Air Vehicles", Dr. Rafal Zbikowski, Cranfield University, England. October 21, 2002
- "Plastic Anisotropy in Metals and Alloys", Dr. Federic Barlat, Alcoa Technical Center, PA. February 20, 2003
- "Finite Elasto-Plasticity of Crystalline Materials", Prof. Sanda Cleja-Tigoiu, University of Bucharest. February 27, 2003

- "The Navigation of Autonomous Vehicles in Uncertain Dynamic Environments Via a Probabilistic Approach", Dr. Myungsoo Jun, Cornell University. May 07, 2003
- "Stability & Application of the Linear Time Invariant, Time Delayed Systems LTI-TDS", Dr. Nejat Olgac, University of Connecticut. March 13, 2003
- "A Particle-Level Set Based Sharp-Interface Eulerian Method for Simulating Impact, Penetration and Void Collapse", Dr. H.S. Udaykumar, University of Illinois. March 19, 2003
- "Micromechanical Approach to the Macroscopic Behavior of Damaged & Poroelastic Materials", Dr. Djimedo Kondo, University of Lille, France. March 27, 2002
- "Desktop Micro Robots Factory and Micro-Hopping Robot", Dr. Hisayuki Aoyama, University of Electro Communications, Japan
- "Arbitrary Discontinuities and Level Sets in Finite Elements Methods", Prof. T. Belytschko. May 19, 2003

6. Scientists in Residence

During the current reporting period 17 visiting scientists were in residence for varying periods at the UFGERC working with AFRL/MN scientists. Extensive interactions between scientists in the three different research focus areas promoted fruitful discussions in multidisciplinary topics.

Personnel Supported

During the current reporting period 17 visiting scientists were in residence for varying periods at the UFGERC working with AFRL/MN scientists. Extensive interactions between scientists in the three different research focus areas promoted fruitful discussions in multidisciplinary topics. The following scientists were supported during stays of varying duration:

Christopher Anderson	University of Florida GERC
Anthony Calise	Georgia Tech
Oana Cazacu	University of Florida GERC
Nicholaie Cristescu	University of Florida
Sathya Hanagud	Georgia Tech
Marc Jacobs	AFOSR
Janusz Klepaczko	University of Metz, France
Kinnan Kline	University of Florida
Pavlo Krokhmal	University of Florida
Andrew Kurdila	University of Florida
Kristi Morgansen	University of Washington
Jeff Shamma	UCLA
Jason Speyer	UCLA
Eric Sutton	University of Florida GERC
Loc Vu-Quoc	University of Florida
Michael Zabarankin	University of Florida
Rafal Zbikowski	Cranfield University, U.K.

The P.I., Pasquale M. Sforza, was supported by University of Florida cost-sharing, while the efforts of AFRL/MN scientists, including the Chief Scientist, Robert Sierakowski, were supported by that organization.

Interactions/Transitions

Professor Andrew Kurdila of the University of Florida reports that a proposal entitled "Vision-Based Control of Agile Autonomous Micro Air Vehicles and Small UAVs in Urban Environments" was approved for funding by AFOSR during this reporting period. Much of the proposal was developed during the summer of this reporting period while he was visiting the GERC as a participant in the Research Institute for Autonomous Precision Guided Systems. Professor Kurdila acknowledges the Research Institute for providing an environment and a stream of outstanding researchers in the field that aided in formulating this successful proposal. Many of the experimental facilities to be developed under the new contract will be located at the GERC, further enhancing the Research Institute capability.